Preamble

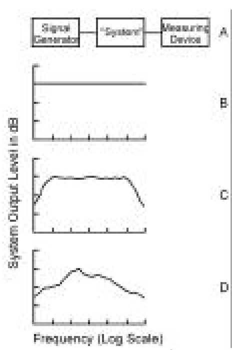
- Deliver sound wave (or electrical signal) to a system
- If the system reproduces the waveform <u>faithfully</u>, the signal is <u>undistorted</u>
- If the shape of the waveform is <u>altered</u>, the signal is <u>distorted</u>

Three Types of Distortion

- Frequency
- Transient
- Amplitude

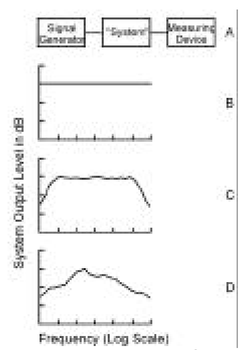
FREQUENCY DISTORTION

- Panel A: Transfer function (amplitude response) of a system is the output when the input has equal amplitude at all frequencies.
- Panel B: No distortion at output of system
- Panels C & D
  - ♦ <u>NOT</u> all frequencies reproduced the same
  - ♦ System was frequency selective; filtering occurred
  - ♦ Signal underwent f<u>requency distortion</u>



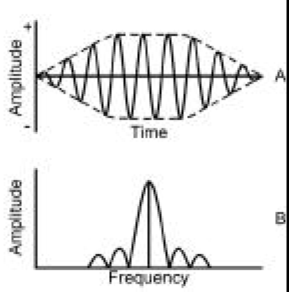
FREQUENCY DISTORTION

- The three functions in panels B, C, & D describe the <u>system transfer function</u>, or <u>amplitude response</u>, of the system
- The amplitude response reveals evidence of frequency distortion
- *Linear systems* (A_{in} A_{out}) produce frequency distortions.



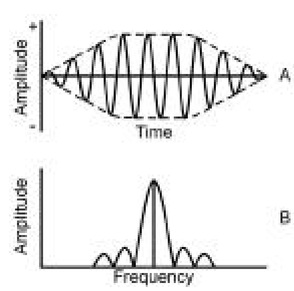
Effects of Rise-Decay Time on Amplitude Response

- Amplitude rises over time from zero to max, and falls over time from max to zero
- Panel A shows <u>amplitude envelope</u> in the time domain
- Panel B shows <u>amplitude spectrum</u> in the frequency domain (frequency spread)
- Initiation & termination of signal produces <u>transients</u>



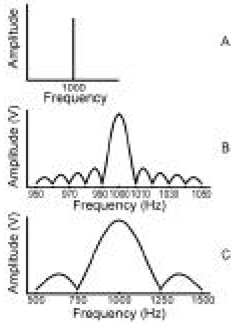
Effects of Rise-Decay Time on Amplitude Response

- ♦ The longer the rise-fall time, the less the transient distortion
- ♦ ANSI S3.6-1989
  - >> Time from -20 dB to -1 dB shall not be less than 20 ms



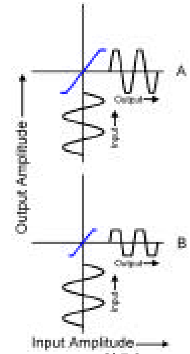
TRANSIENT DISTORTION

- A sine wave of infinite time.
- B sin of finite time. (100 ms)
- C sin of short time. (4 ms)
- Energy spread to surrounding frequencies, and amplitude spectrum is continuous
- Why?
  - Its duration is finite
- Nulls at integer multiples of reciprocal of duration and width of each lobe is inversely proportional to duration
- (1/.1=10 and 1/.004=250)



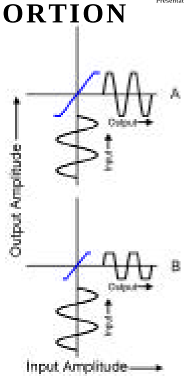
AMPLITUDE DISTORTION

- Panel A: Do some of the instantaneous amplitudes of the input signal exceed the limits of linearity of the system?
  - ☑ Yes
- What is the result?
  - ☑ The instantaneous amplitudes at or near maximum amplitude are "clipped off"-- output amplitude is not proportional to input amplitude -- the signal has been peak clipped; distortion
- Panel B: more severe peak clipping; more severe distortion



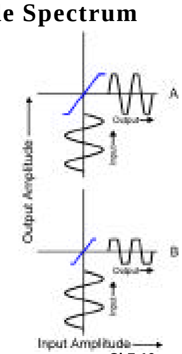
AMPLITUDE DISTORTION

- The distortion is called amplitude distortion; Why?
  - ☑ Amplitude is the waveform parameter that was altered
- Amplitude distortion is also called nonlinear distortion; Why?
  - ☑ The distortion arose from operating on the nonlinear portion of the I / O function



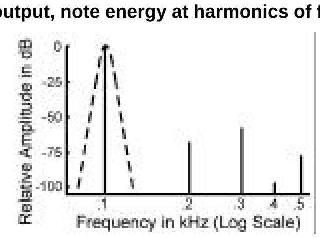
Effects of Amplitude, or Nonlinear, Distortion on Amplitude Spectrum

- Input signals in panels A & B are sinusoids
- Output signals are what kind of sound waves?
  - ☑ Complex periodic waveforms
- At what frequencies should you expect to see energy in a complex periodic waveform?
  - ☑ Harmonics
- Thus, amplitude, or nonlinear, distortion also can be called harmonic distortion (if the input waveform is sinusoidal)



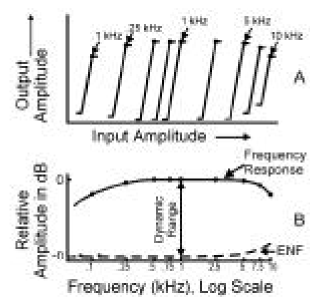
Effects of *Amplitude*, *Nonlinear*, or *Harmonic* Distortion on Amplitude Spectrum

- The figure displays the output spectrum from a nonlinear system
- At the input, f = 100 Hz
- At the output, note energy at harmonics of f_0



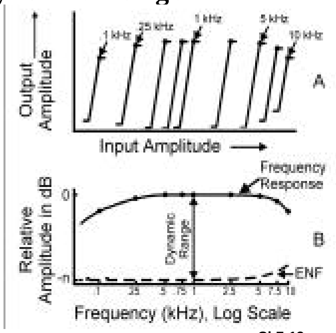
Amplitude Response and Dynamic Range

- Panel A: I / O functions for several driving frequencies from .1 kHz to 10 kHz
  - » On each I / O function, location of the filled dot identifies point of maximum permissible harmonic distortion
- Panel B: The dots from I / O functions are connected and redrawn in the frequency domain to form the upper curve
  - » That defines the amplitude response of the system
  - » Electrical noise floor (ENF) of system is shown by lower curve



Amplitude Response and Dynamic Range

- Dynamic range is distance in decibels from ENF to amplitude response at maximum
- Does ENF vary with frequency?
  - ☑ Yes



What should you know?

- Frequency Distortion
  - dynamic range or system transfer function
  - not all frequencies are treated equally
  - results in some frequencies being attenuated
- Transient Distortion
  - finite vs infinite signal (rise and fall time)
  - not a line spectrum
  - results in spectral components being broaden
- Amplitude Distortion
  - system cannot handle the amplitude range
  - peak or amplitude clipping
  - results in harmonics being created

Intermodulation Distortion

- Driving signal is complex
- Experience nonlinear distortion
- Result called intermodulation distortion

Intermodulation Distortion

- Suppose input signal has two frequency components
  - f_1 = 100 Hz
  - f_2 = 110 Hz
- Frequency components of output signal include two types of distortion products:
  - Harmonics
  - Combination Tones
    - >> Difference tones
    - >> Summation tones

Intermodulation Distortion

- 1. Harmonics of each frequency component
  - $1f_1$ = 100 Hz & $1f_2$ = 110 Hz
  - $2f_1$ = 200 Hz & $2f_2$ = 220 Hz
  - $3f_1$ = 300 Hz & $3f_2$ = 330 Hz, etc.

Table 7-2. Examples of harmonics and combination tones produced for a complex wave with two frequency components, f_1 = 100 Hz and f_2 = 110 Hz

HARMONICS OF f_1	HARMONICS OF f_2	COMBINATION TONES Difference Tones	COMBINATION TONES Summation Tones
$\|1f_1 + 0f_2\| = 100$	$\|0f_1 + 1f_2\| = 110$	$\|1f_1 - 1f_2\| = 10$	$\|1f_1 + 1f_2\| = 210$
$\|2f_1 + 0f_2\| = 200$	$\|0f_1 + 2f_2\| = 220$	$\|2f_1 - 1f_2\| = 90$	$\|2f_1 + 1f_2\| = 310$
$\|3f_1 + 0f_2\| = 300$	$\|0f_1 + 3f_2\| = 330$	$\|3f_1 - 1f_2\| = 190$	$\|3f_1 + 1f_2\| = 410$
etc.	etc.	etc.	etc.

Intermodulation Distortion

- 2. Difference tones:
  - $|1f_1 - f_2|$ = 10 Hz
  - $|2f_1 - f_2|$ = 90 Hz
  - $|3f_1 - f_2|$ = 190 Hz, etc.

Table 7-2. Examples of harmonics and combination tones produced for a complex wave with two frequency components, f_1 = 100 Hz and f_2 = 110 Hz

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$\|2f_1 + 0f_2\| = 200$	$\|0f_1 + 2f_2\| = 220$	$\|2f_1 - 1f_2\| = 90$	$\|2f_1 + 1f_2\| = 310$
$\|3f_1 + 0f_2\| = 300$	$\|0f_1 + 3f_2\| = 330$	$\|3f_1 - 1f_2\| = 190$	$\|3f_1 + 1f_2\| = 410$
etc.	etc.	etc.	etc.

Intermodulation Distortion

- 3. <u>Summation</u> tones:
  - $1f_1 + f_2 = 210$ Hz
  - $2f_1 + f_2 = 310$ Hz
  - $3f_1 + f_2 = 410$ Hz, etc.

Table 7-2. Examples of harmonics and combination tones produced for a complex wave with two frequency components, $f_1 = 100$ Hz and $f_2 = 110$ Hz

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etc.	etc.	etc.	etc.

Combination Tones

- Equation 7.3 defines frequencies of all harmonics, difference tones, and summation tones
  - $mf_1 \pm nf_2$, where
  - m and n are assigned all integer values

Linear Systems

- Linear systems alter only the amplitudes and phases of a signal
- They <u>do</u> produce frequency distortion
- “Frequency response” of an audio device might be described as
  - 100 Hz to 10,000 Hz
  - Flat ± X dB

Linear Systems

- Panel A: Input-Output (I/O) function of <u>linear</u> system
  - As input amplitude increases (e.g., 5 dB), output amplitude increases <u>proportionally</u> (5 dB)
  - Output amplitude need not <u>equal</u> input amplitude; the change is a proportional one
- Panel B: The characteristics of the input sine wave are <u>preserved faithfully</u> in output sine wave; Why?
  - ☑ The system is linear